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DISTINCTION OF THE NILE DELTA COASTAL ENVIRONMENTS BY SCANNING ELECTRON MICROSCOPY: A STATISTICAL EVALUATION

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ABSTRACT

Sand grain surface textures were examined from modern Nile Delta coastal deposits of known origin that had been subjected to mechanical and chemical processes during erosion, transportation and deposition. Samples representing breaker zone, beach, backshore, dune and River Nile sands were selected to establish characteristic grain surface textures. There are no simple diagnostic features for any particular environmental history because different mechanical processes produce similar surface features on sand grains. Only by quantitative analysis of sand grain surface feature abundances can accurate evaluation be made.

INTRODUCTION

DAVID KRINSLEY and his associates pioneered the field of electron microscopy as used on quartz grains [KRINSLEY and TAKAHASHI, 1962; KRINSLEY and DONAHUE, 1968; KRINSLEY and MARGOLIS, 1969; 1971; KRINSLEY and DOORNKAMP, 1973; MARGOLIS, 1968; MARGOLIS and KENNETT, 1971]. With the development of the SEM, however, examination of a sand grain at magnifications up to 10.000 power is accomplished quickly and easily by anyone having access to a machine. The advent of the SEM has made this type of analysis a relatively simple procedure and consequently a viable approach to the solution of appropriate sedimentological problems. As a result, numerous papers have been published during the last decade, dealing with the specialized use of the SEM and suggesting the use of various surface textures on sand grains as environmental indicators [BLACKWELDER and PILKEY, 1972; KRINSLEY *et al.*, 1973; INGERSOLL, 1974; BAKER, 1976; FRIEDMAN *et al.*, 1976; MANKER and PONDER, 1978; HIGGS, 1979; BULL, 1981; CULVER *et al.*, 1983].

The goal of the study of grain surfaces has been the identification of surface markings on sand grains that are uniquely produced by a specific transport process. Thus far, satisfactory results have been obtained predominately from the examination of unconsolidated sediments and from artificially abraded crushed quartz. A summary with photomicrographs of the criteria useful in surface texture texture interpretation has been provided by KRINSLEY and MARGOLIS [1971] and KRINSLEY and DOORNKAMP [1973]. To date, these methods require treatment or simple non-parametric statistical analysis.

Sand grain surface textures were examined along the Nile Delta coast. Samples were collected from the breaker zone, beach, backshore, coastal dune and River Nile (*Fig. 1*). The aims of the present study are:

1. To examine the sand grain surface textures of the Nile Delta coastal environments. In fact, the distinction between breaker zone and beach sands, and that between backshore and dune sands, do not attract the attention of many authors.

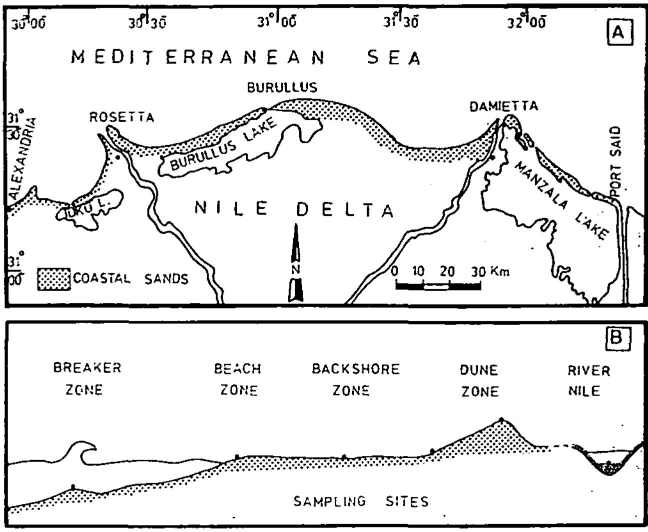

Fig. 1. Location map showing the studied area *(A)*, and sampling sites *(B)*.

2. To evaluate quantitatively whether the surface textures can be relied upon to distinguish accurately between various environments, and whether this should be done on the basis of single or groups of feature.

GRAIN SIZE STUDIED

All investigators seem to agree that sands finer than 250 μm show a relative predominance of chemical features, while coarser sands do that of mechanical features. In the present study, the average grain size in all samples was about 700 μm in diameter, and ranged from 250 μm to 2000 μm. No relationship was observed between grain size and surface texture. About 60 grains of each environmental deposit were examined at approximately 4000× to determine what features might be present. Photomicrographs were made for the grains examined and the most interesting ones are produced in this study.

RESULTS

Grain surface features for breaker zone, beach, backshore, coastal dune and River Nile sands are shown in Plates I—V, respectively. The various surface features recognized in coastal sands are enumerated below.

Littoral environments

These include grains obtained from breaker zone, beach and River Nile sands (Plates I, II, V). The grains affected by littoral action are characterized by V-shaped patterns, straight and curved scratches and grooves with steep and irregular sides, conchoidal fractures and irregular breakage blocks. These features are generally found on the edges of the grains, but may be observed on other grain surface. Numerous grain collision micro-textures and small impact pits were observed. Semi-parallel steps which characterize glacial origin were seen on a few grains from breaker

TABLE 1

Widths, depths and diameters for some surface features

Feature		Breaker zone	Beach	River Nile
V-shaped pits	width:	2— 20 μm	2.0—33 μm	2—10 μm
	depth:	1— 15 μm	0.2— 6 μm	1— 3 μm
Scratches	width:	16—100 μm	12.0—50 μm	5—70 μm
	depth:	2— 10 μm	1.0— 5 μm	1— 5 μm
Breakage blocks	diam:	20— 50 μm	15.0—50 μm	3—30 μm

zone and beach sands. On some grain surfaces, the littoral solution attacked collision grooves, grain edges and breakage corners, and produced solution precipitation surfaces and small deep surface etching.

It is possible to distinguish between high and low wave energy environments on the basis of surface texture. The photomicrographs show sharp scratches and grooves with aligned breakage blocks and deep V-shaped pits, which may be considered as the diagnostic features of high-energy environments (breaker zone, Plate I). These features are easily recognized on most grains; they often coincide with the edges of conchoidal breakage patterns of V-shaped pits. Table 1 summarizes the widths and depths for some surface features of the littoral environmental sands.

KRINSLEY and MARGOLIS [1971] reported that the V-shaped patterns have an average depth of 0.1 μm and there is an average density of two V's per square micron. In the samples of the present study, there was much a wide variation in size and depth of this pattern that no such generalizations seem warranted. V-shaped pits, scratches and grooves of breaker zone sands, however, are relatively deeper, wider and longer than those of beach and river sands. INGERSOLL [1974] stated that the depth and width of the V-shaped pits are probably due to crystalline structure, grain size and mechanical versus chemical effects.

Aeolian environments

SEM examination showed that mechanical abrasion features are commonly considered to be characteristic of aeolian sands with surface features dominated by chemical precipitation. Plates III and IV show the diagnostic features for backshore and dune sand grains. Meandering ridges, mechanically upturned plates, dish-shaped concavities, graded arcs and polygonal cracks are characteristics of aeolian action. Scratches and grooves, mechanical pits, cleavage planes and solution precipitation surfaces also occur.

The conchoidal pattern and blocky breakage of aqueous origin may be rapidly abraded and merge into meandering ridges under the wind action. The upturned plates of various sizes, but no larger than 3 μm high, may extend unbroken for 60 μm or more, or may be broken and discontinuous. Additionally, they may be gyreatl subdued or rounded off by solution and precipitation. Rounded, dish-shaped concavities are observed on some grain surfaces. Flat cleavage plates and plate ends are frequently lightly covered by a smooth precipitated layer.

A comparison between backshore and coastal dune sand grains leads to some diagnostic features. In backshore sands, some of the examined grains are characterized by V-shaped patterns and breakage blocks, which indicate their beach origin

(Plate III). On the other hand, there are sand grains derived from coastal dunes as testified by the polygonal cracks and deep surface etching (Plate IV). The backshore zone may be considered as a transitional zone between the beach and the coastal dune.

Statistical evaluation

Attempts to estimate the percentage occurrence of the grain surface covered by each feature proved to be highly subjective and very time-consuming. A simple presence or absence (binary data) was tabulated for each feature, to yield the percentage occurrence in this study. Questionable occurrences were tabulated as absent. Twenty textural features were selected for evaluation of their sensitivity in differentiating the Nile Delta coastal environmental sands (Table 2). These features were catalogued by KRINSLEY and DOORNKAMP [1973]. The polygonal cracks were originally identified on desert grains from Libya by LUCCI [1971] and supported by BAKER [1976].

A comparison of percentages occurrence of surface features for breaker zone, beach, backshore, dune and River Nile sands revealed significant difference, as shown in Table 2 and *Fig. 2*. On the grand scale of comparing aqueous features with aeolian ones, only 5 features proved to be distinctive. The V-shaped pattern, conchoidal fractures, breakage blocks, straight scratches and grooves, and stepped cleavage surfaces almost invariably occur together and may be considered as a single class of abrasional

TABLE 2

Percentage occurrences of surface features for coastal sands

Surface features	River Nile	Breaker zone	Beach zone	Backshore zone	Dune zone
Chemical					
Smooth precipitation surface	7.69	19.30	12.82	5.41	47,16
Irregular precipitation surface	23.08	5.26	2.56	5.41	13.21
Precipitated upturned plates	0.00	5.26	0.00	5.41	5.66
Precipitation in grooves	19.23	7.02	30.77	10.81	24.53
Adhering particles	11.54	14.03	23.07	24.32	9.43
Deep surface etching	7.69	5.26	7.96	0.00	9.43
Oriented V-shapes patterns	7.69	3.51	0.00	0.00	0.00
Mechanical					
Conchoidal fractures	3.85	35.09	25.64	0.00	0.00
Breakage blocks	19.23	29.82	28.21	8.11	0.00
Straight scratches and grooves	50.00	47.37	35.90	21.62	26.42
Curved scratches and grooves	73.08	73.68	66.67	54.05	35.85
Mechanical pits	50.00	42.10	28.21	29.73	49.06
Cleavage planes	11.54	21.05	33.33	27.03	13.21
Stepped cleavage surface	0.00	7.02	12.82	0.00	0.00
Mechanical V-shaped patterns	38.46	78.95	58.97	16.21	3.77
Mechanically upturned plates	7.69	3.51	2.56	24.32	24.53
Meandering ridges	0.00	0.00	0.00	27.03	50.94
Dish-shaped concavities	0.00	1.75	2.56	10.81	11.32
Polygonal cracks	0.00	0.00	0.00	0.00	7.55
Graded arcs	0.00	0.00	0.00	8.11	11.32

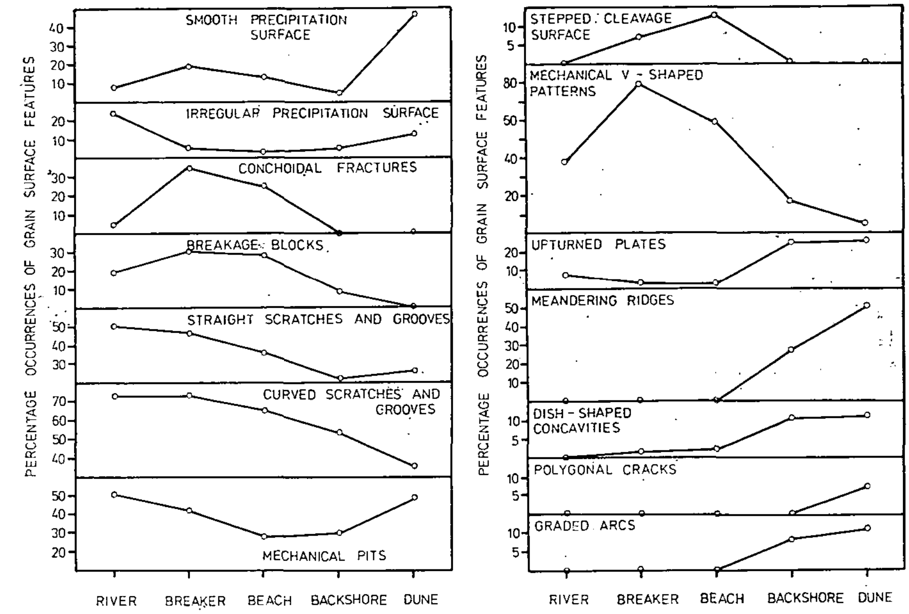

Fig. 2. Percentage occurrences of grain surface features for coastal sands.

features. These features occur on between 30% and 80% of the grains throughout the littoral sands, but on fewer than 20% of the grains from the aeolian sands. They also occur on fewer than 40% of the River Nile sands; MARGOLIS and KENNETT [1971] mentioned that they occur on fewer than 50% of the grains taken from river sands. The presence of these features on aeolian sands is not considered diagnostic of non-marine origins, because they do not occur in abundance. Remembering the shoreline history of the backshore flat and coastal dune sands, it seems probable that these features present in the aeolian sands are inherited and their preservation is possible. Besides this preservation, new features are created due to the wind action, which leads to an abundance of upturned plates, meandering ridges, dish-shaped concavities, graded arcs and polygonal cracks on aeolian sand grains.

Although progress has been made in relating quartz grain surface features to specific transport (depositional environments), little attention is given to the features produced by fluvial systems. In the present study, some significant variations were found between littoral sands (breaker zone and beach) and river sands. Littoral sands are characterized by an abundance of V-shaped pits, conchoidal fractures and stepped cleavage surfaces, while the river sands show an abundance of irregular precipitation surfaces and mechanical pits and a higher percentage of oriented V-shaped pits. On the other hand, the breaker zone sands are characterized by more V-shaped pits, conchoidal fractures, scratches and grooves than on the beach sands. As regards the aeolian sands, smooth precipitation surfaces, mechanical pits, meandering ridge sand polygonal cracks occur in higher percentages on the coastal dune sands than on the backshore ones.

The results of this study are consistent with the origins of the micro-textures postulated by KRINSLEY and his students. Those features thought to be most diag-, nostic of a littoral setting, such as mechanical V-shaped pits, conchoidal fractures breakage blocks, scratches and grooves and stepped cleavage surfaces, markedly decrease in abundance in a landward direction (from breaker zone through beach and backshore and up to the dune). In contrast, those features thought to be diagnostic of aeolian processes, such as upturned plates, meandering ridges, dish-shaped concavities and graded arcs, increase in a sharp manner. The inland decrease in abundance of the high-energy impact features is logical in that the breaker zone and surf zone are certainly the most persistent high-energy zones along the coast.

It is likely that different mechanical processes produce similar surface features on sand grains *(Fig. 2,* Table 2). Only by quantitative analysis of sand grain surface feature abundances, in addition to other sedimentary information, can accurate evaluation be made. Although it may be true that certain features act as more important environmental indicators, whilst others serve as cosmetic detail, it is not necessarily true that the same textures are the pre-eminent discriminators in every case. Thus, there are no simple diagnostic features for any particular environmental history. This result supports the methodology of MARGOLIS and KENNETT [1971], WHALLEY and KRINSLEY [1974] and CURVER *et al.,* [1983].

CONCLUSIONS

1. Scanning electron microscopy examination of the grain surface texture was performed on the Nile Delta coastal deposits. It is possible to distinguish between river, breaker zone, beach, backshore and coastal dune sands in the basis of surface textures. The grain surface features may be applied to the study of ancient deposits.

2. V-shaped pits, conchoidal fractures, breakage blocks, scratches, grooves and stepped cleavage surfaces appear to be good indicators of subaqueous environments. Upturned plates, meandering ridges, dish-shaped concavities, graded arcs and polygonal cracks may be used tentatively as indications of proximity to aeolian environments.

3. Attempts to estimate the percentage occurrence of the grain surface covered by each feature proved to be highly subjective and revealed significant differences between environments. The subaqueous features occur on between 30% and 80% of the grains throughout the breaker zone and beach sands, but on fewer than 40% of the grains from the river sands. The presence of these features on fewer than 20% of the aeolian grains is not considered diagnostic of non-marine origins. Remembering the shoreline history of the backshore and coastal dune sands, it seems probable that these features present in the aeolian sands are inherited and their preservation is possible. Besides this preservation, the aeolian features are created due to wind action.

4. The subaqueous features markedly decrease in abundance, while the aeolian features increase sharply in the landward direction (from the breaker zone across the beach and backshore and up to the dune). It is likely that different mechanical processes produce similar surface features, and only by quantitative analysis of surface feature abundances can accurate evaluation be made.

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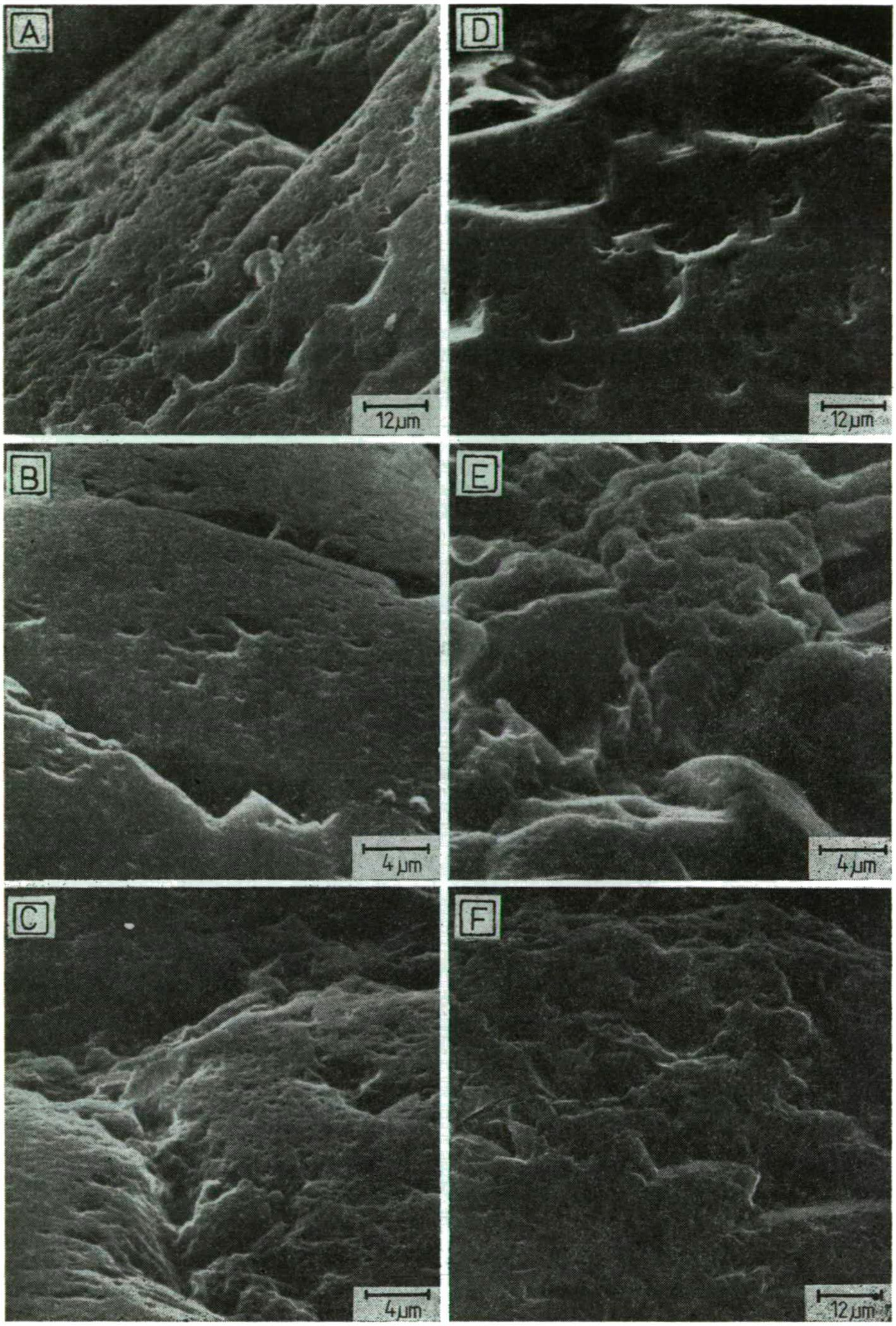
PLATE I



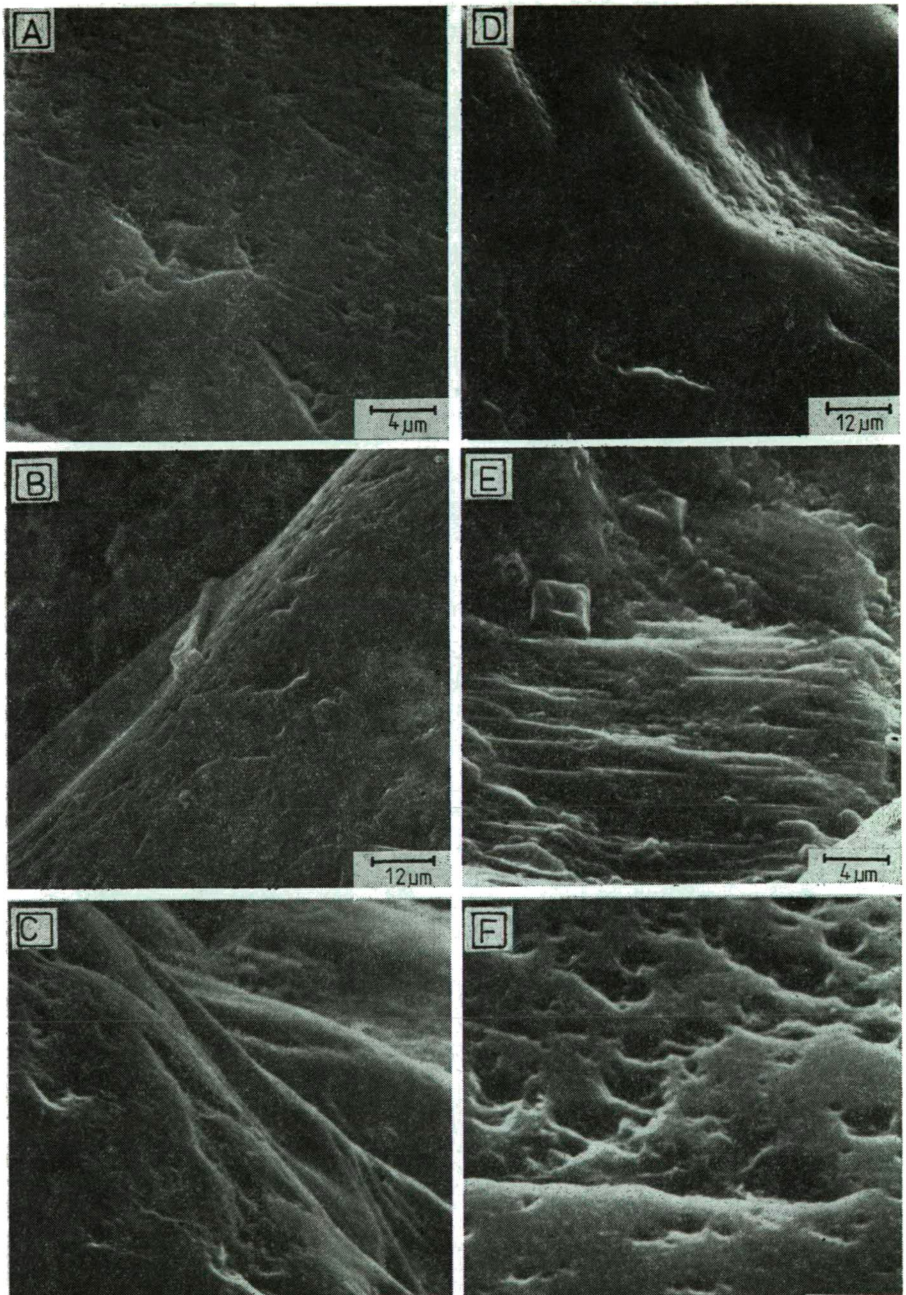

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PLATE III

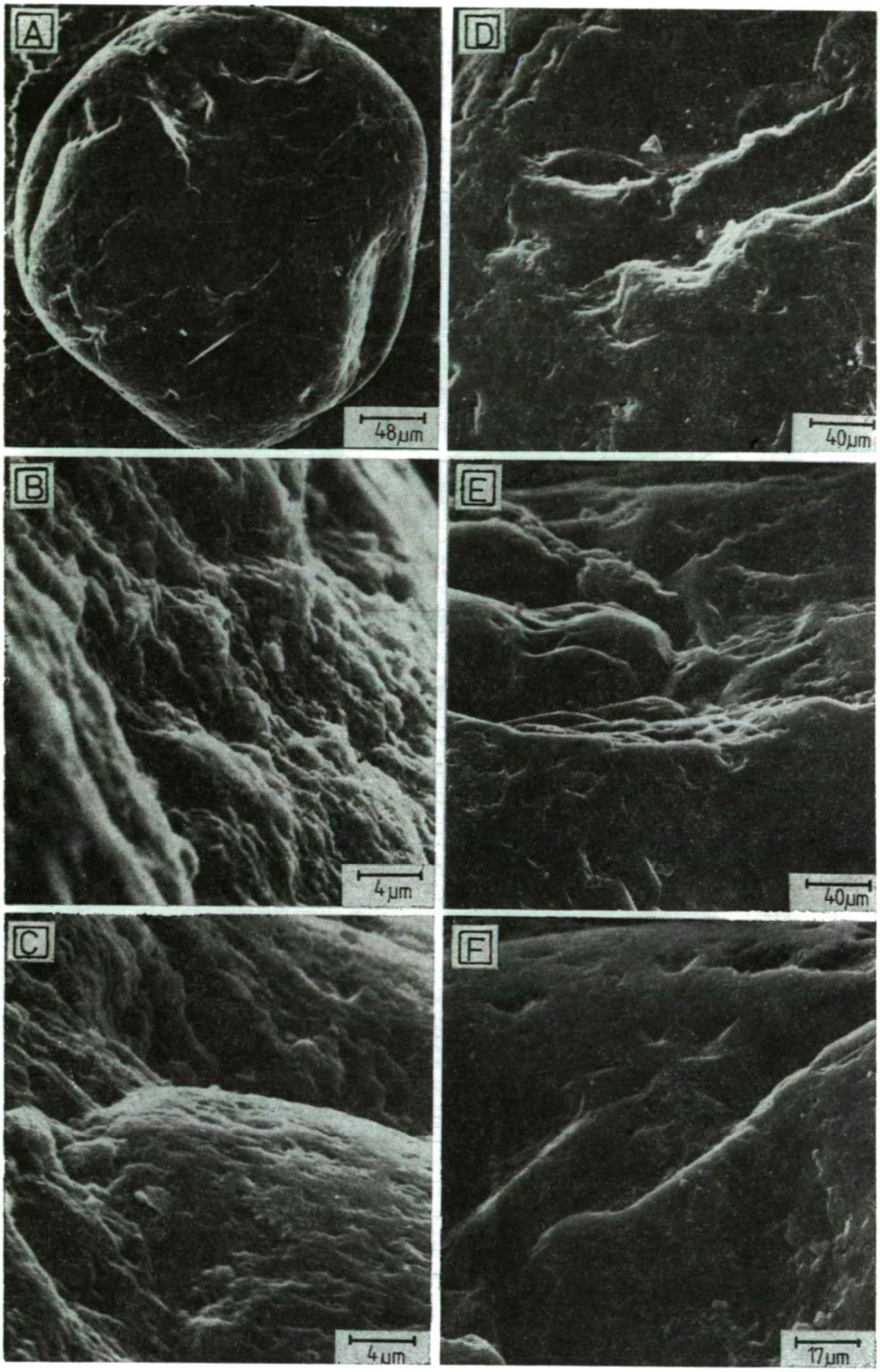
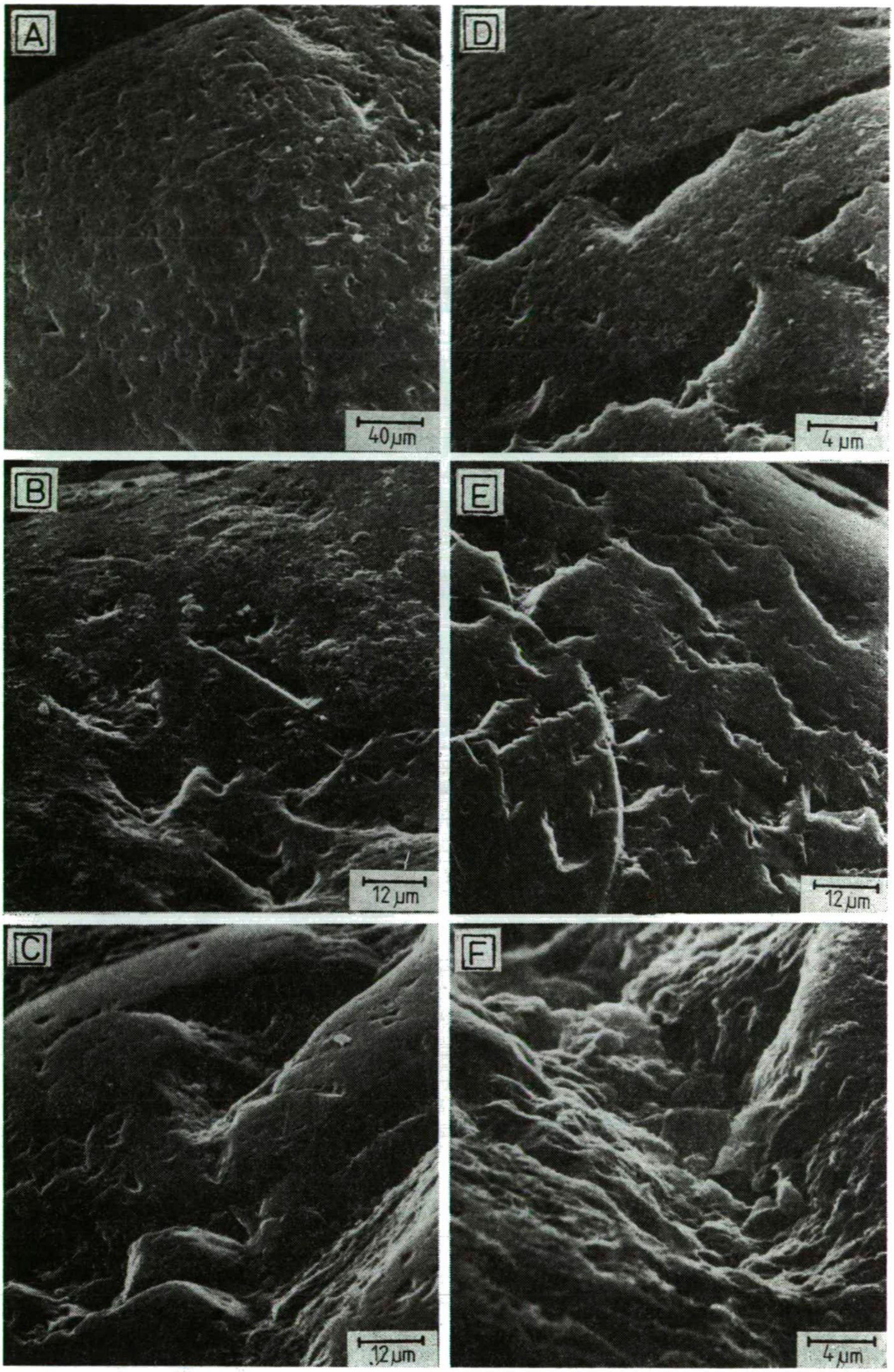


PLATE V



EXPLANATION OF PLATES I-V

PLATE I: Scanning electron micrographs of breaker zone sand grains. A: V-shaped patterns and pits. B: V-shaped patterns and straight groove. C: Curved grooves. D: V-shaped and straight scratches. E: Blocky conchoidal breakage pattern. F: Stepped cleavage.

PLATE II: Scanning electron micrographs of beach sand grains. A: V-shaped patterns and straight scratches. B: Pits and curved scratches. C: Blocky conchoidal breakage patterns. D: Curved scratches and grooves. E: Chemical precipitation. F: Etching surface.

PLATE III: Scanning electron micrographs of backshore sand grains. A: Dish-shaped concavities. B: Upturned plates. C: Precipitation surface. D: Cleavage planes and grooves. E: Breakage blocks, pits and scratches, F: V-shaped pattern indicating subaqueous origin.

PLATE IV: Scanning electron micrographs of coastal dune sand grains. A: Dish-shaped concavities, V-shaped patterns and pits. B: Meandering ridges. C: Upturned plates and precipitation surface. D: Polygonal cracks. E: Graded arcs and precipitation. F: Straight scratches and precipitation.

PLATE V: Scanning electron micrographs of River Nile sand grains. A: Pits scratches and grooves. B: Oriented V-shaped patterns and chemical precipitation. C: V-shaped patterns and grooves. D: V-shaped patterns and scratches. E: Breakage blocks and scratches. F: Precipitation in grooves.